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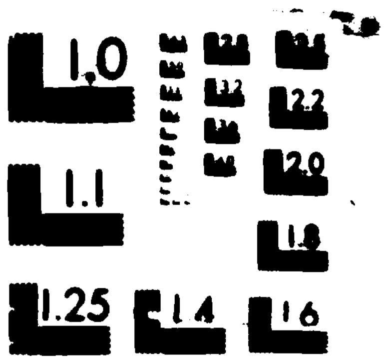

MICROCOPY RESOLUTION TEST CHART

AFWAL-TR-87-1002

LASER INTERCEPT RECEIVER

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Passive Electronics Countermeasures Branch
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January 1987

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AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

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This report summarizes the in-house evaluation of the Laser Intercept Receiver built by Tracor Aerospace, Austin, Inc. Baseline performance measurements were conducted to characterize field-of-view, sensitivity and dynamic range.

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FOREWORD

This report summarizes the in-house evaluation of the Laser Intercept Receiver, built by Tracor Aerospace Austin, Inc. The receiver is of interest to the Air Force because it incorporates state-of-the-art technologies for radiometric laser detection at three wavelengths: 514nm, 532nm, and 1064nm. A radiometer by definition, the Laser Intercept Receiver (LIR) may find applications in future Air Force model validation and field measurement experiments. Baseline performance measurements were conducted at the AFWAL/AAWP-2 Electro-Optics Laboratory from 10 August 1986 to 01 September 1986. The measurements included field-of-view mapping, frequency response, sensitivity, and dynamic range under background illumination conditions. The authors would like to thank the following individuals for their contributions to the evaluation effort: Mr Angelo Lombardo and Mr Robert Potter for assistance in experimental setup and data collection; and Mrs Natalie Herstine for her clerical support.

SECTION I: SYSTEM DESCRIPTION

1. OVERVIEW:

The Laser Intercept Receiver (LIR) radiometer described in this report is part of a continuing effort to improve methods of interception and characterization of laser radiation to be used in Air Force field experiments in this area, as well as for possible deployment in Air Force platforms. This receiver was developed by Tracor under Internal Research and Development activities. The objective of the LIR program was to develop a multi-wavelength optical receiver capable of intercepting optical signals in an off-axis position and measuring the parameters of that signal input into a list of optical intelligence parameters. The LIR was to be capable of intercepting the most commonly used laser wavelengths and capable of demodulating the various encoding methods employed. In addition, the LIR was intended to be portable and easily deployed. A photograph of the LIR system is shown below:

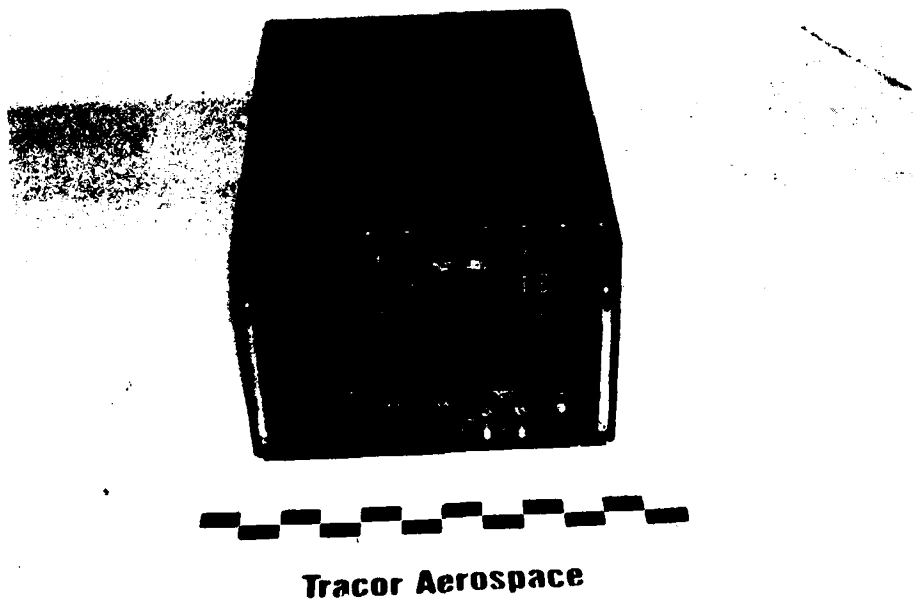

Figure 1. LIR System

1. OVERVIEW (Cont):

It has an external power supply which can provide battery or AC power. The LIR has three outputs: a video output which contains a representation of the detected signal, a demodulation output which provides a demodulated representation of the video output useful for optical communication scenarios, and a TTL output which is triggered by pre-setable threshold adjustments. The threshold circuitry permits artificial simulation of receiver signal-to-noise conditions. Separate channels can be selected to operate at three different wavelengths: 514nm, 532nm, and 1064nm. Video filters are utilized to provide the capability of operating at three bandwidths; 20KHz, 3MHz, and 40MHZ. There are three gain settings for the avalanche photodiode detector; minimum, maximum, and auto gain. The auto gain provides dynamic compensation for input signal level. The receiver contains a rifle telescope for boresighting.

2. OPTICAL:

The following section is an extract from a Tracor design description of the receiver's optics train. A block diagram of the optical elements is shown in Figure 2. The optical subsystem consists of a 4x a-focal achromatic magnifier, a dichroic mirror, narrow bandwidth filters, plastic aspheric lenses, and avalanche photodiodes. The plastic aspheric lenses were selected due to their small blur circle (less than 0.001 inch) and their speed (f/1.1). The a-focal magnifier converts the 1-inch aperture with a 32-milliradian field-of-view into a 4-inch aperture with an 8-milliradian field of view. This optical design has the advantage of providing collimated image space for filtering while simultaneously providing magnification and an expanded field-of-view.

The dichroic beam splitter separates the longer wavelengths (900-1064nm) from the shorter wavelength (500nm). A bandpass filter (with a 3nm FWHM passband and 60 percent transmission at the peak) extracts the 1064nm laser radiation for focusing by a 25mm focal length plastic aspheric lens on a RCA C30950E avalache photodiode. Light reflected from the dichroic mirror is bandpass limited by a blocking filter before being reflected onto a bandpass filter oriented at 30° with respect to the incident radiation. The bandpass filter is centered at 532nm (with a 2nm FWHM passvabd and 55 percent transmission at the the peak.) A folding mirror directs the reflected collimated light onto a third filter centered at 514nm (with a 2nm FWHM passband and 55 percent transmission at the peak). After passing through each filter, the radiation is focused by 25mm-focal-length aspheric lenses onto RCA C30950E avalanche photodiodes. To ensure that the wavelengths of interest are optimally centered in the narrow passbands of the blocking filters, each filter can be finetuned by tilting up to 1 degree off perpendicular.

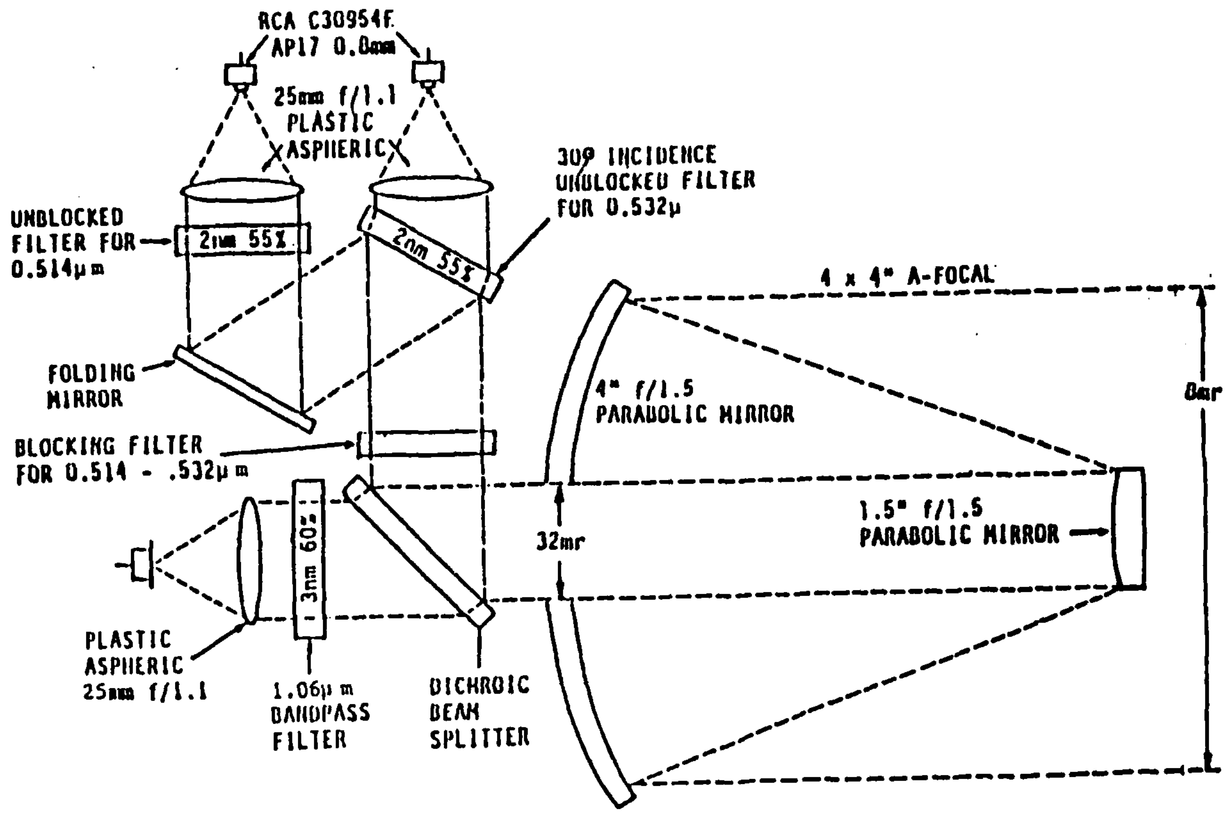

Figure 2. Diagram of Laser Intercept Receiver Optics

3. **ELECTRICAL:** A simple electrical block diagram of the LIR is shown in Figure 3. The principal elements are the power supply for the avalanche photodiodes, amplifiers, threshold detector, automatic gain control, and the video output. The primary power supply consists of two rechargeable 6-volt cells which supply +6 and -6 volts to all detection circuitry. The cells also supply the high voltage power supply which drive the avalanche photodiodes. The output of the selected detectors preamplifier is fed into a wideband amplifier with variable gain, then to a DC restoration circuit, and finally to a high-speed comparator and an integrator. The integrator circuit establishes the average value of the detected signal. The output of the integrator is also fed into a programmable amplifier with selectable gain (x3, x5, x7, x10, and variable). Finally, the video output available at the front panel is simply the buffered and filtered output of the wideband amplifier. The video output has front-panel-selectable low-pass-filter bandwidths of 40MHz, 30MHz, and 20KHz.

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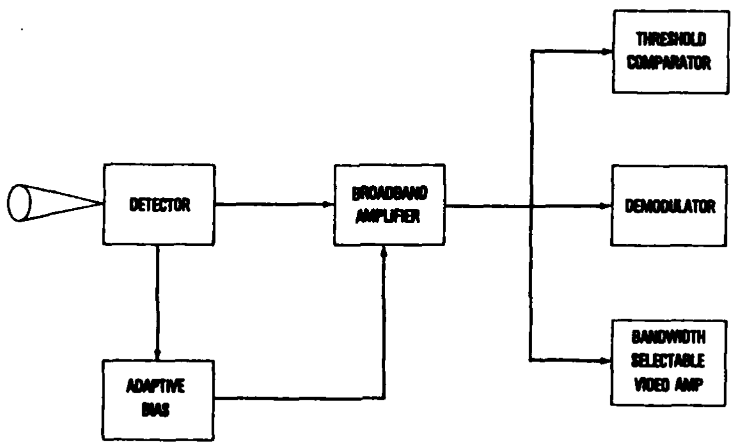


Figure 3. Electrical Path of LIR

SECTION II: MEASUREMENT CONDITIONS

1. TEST CONFIGURATION:

Sources and Optics:

(1) The arrangement of the optical train used to evaluate the LIR is shown in Figure 4. The raw laser beam is reflected from a turning flat to a concave mirror (f=33mm) which focuses the beam at a point coincident with the focal point of an 8-inch off-axis paraboloid (f=100 inches). This in turn produces an 8 inch collimated beam that is directed toward the sensor by way of another turning flat. The radiometer was placed in the beam on a single axis rotary table with the rotary axis in the plane of the entrance aperture.

(2) Tests were performed at three wavelengths: 514nm, generated by a Spectraphysics argon laser model 165, and 532nm, and 1064nm wavelengths generated by a Chromatix Model 1000 Laser. The Blackbody scheme shown in Figure 5 was also used to obtain a second set of results to validate the 1064nm measurements.

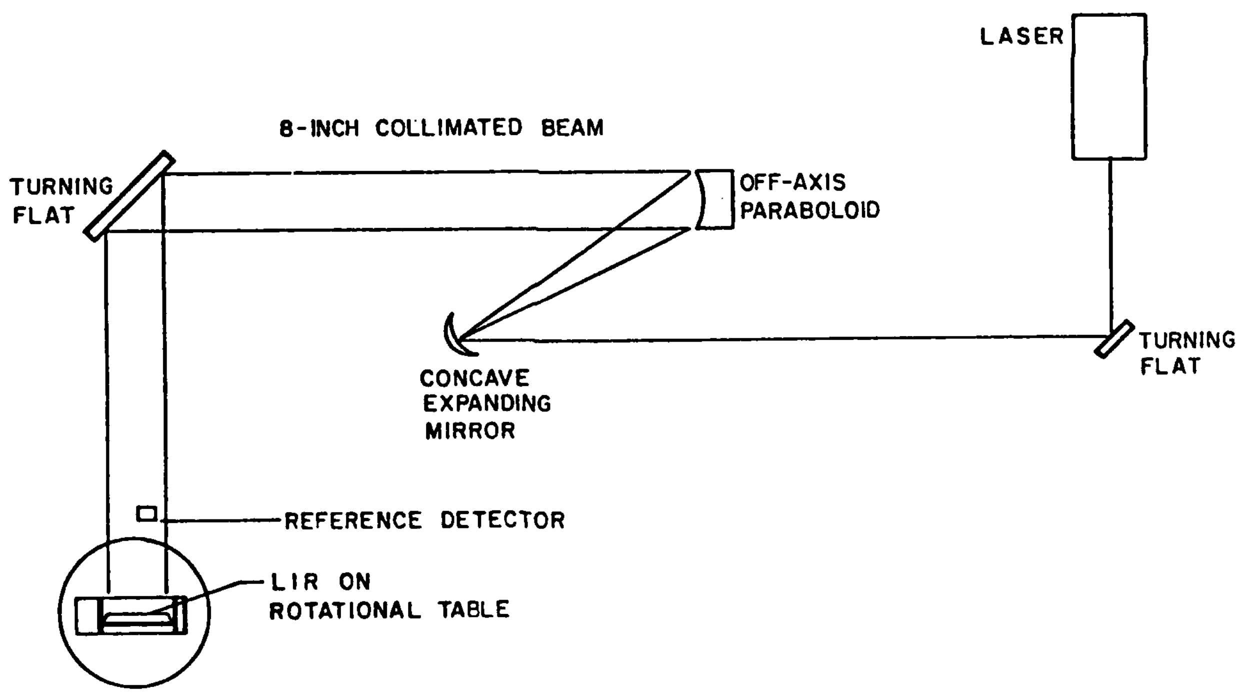


Figure 4. Optical Train Used to Evaluate LIR

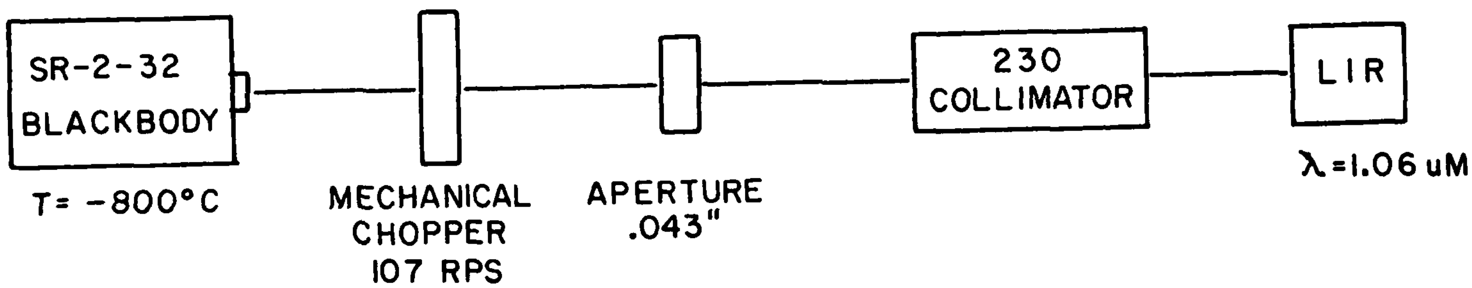


Figure 5. Blackbody Scheme Used to Validate 1064nm Measurements

SECTION III: EXPERIMENTAL RESULTS

1. **DATA SUMMARY:**

a. **Intent:** The data collected during the test was tailored to satisfy four measurement objectives: field-of-view, frequency response, sensitivity, and dynamic range under background illumination conditions.

b. **Field-Of-View Measurements (FOV):** To accomplish the FOV measurements the LIR was set on the rotary table and rotated in azimuth angle with respect to the incoming collimated laser beam. A 4402 EG&G signal processor and 4422 integrator were used to measure peak voltages from the LIR BNC video output. Simultaneous strip charting of the 4402 output and the rotary table position allowed us to accurately map the FOV of the LIR. The FOV was measured at 11.7 mradians. Contractors specification was 8 mradians. The strip chart curves of the FOV map are shown in Figure 6.

c. **Low Frequency Response Measurements:** The configuration utilized to accomplish the frequency response measurements is shown in Figure 7. The argon 514nm CW laser was used along with a mechanical chopper, the speed of which could be manually controlled. The chopper speed was varied from 31KHz down to 1.7KHz which was determined to be the -3db point. This measurement identified the low-frequency-response knee to be at 1.7KHz. Since the LIR is an AC coupled device, it was of interest to measure the low frequency response because the instrument cannot be used for CW light measurements.

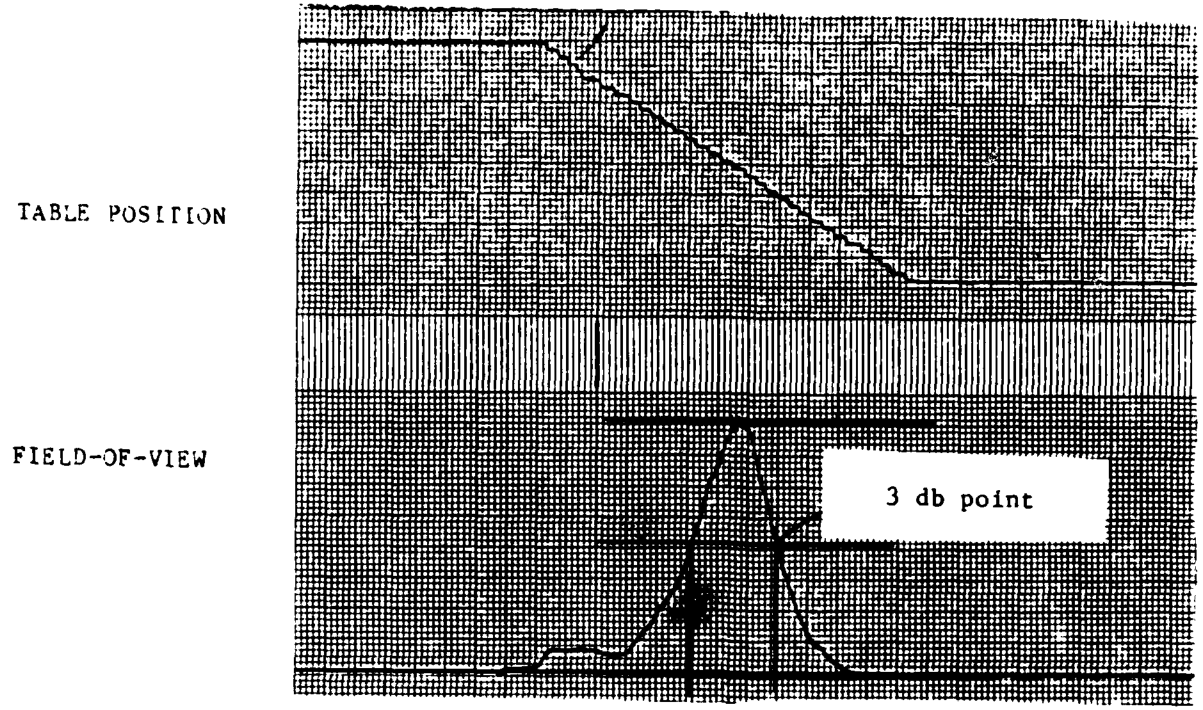
d. **Sensitivity Measurements:**

(1) **Definition:** Threshold sensitivity measurements were conducted atthe three wavelengths described. The definition for threshold was the irradiance required to create a convenient signal-to-noise ratio.

(1) **Procedure:**

(a) Tests were conducted on three different gain settings at each wavelength: minimum, maximum, and auto gain. Each one of these gain settings was then subdivided further into three different bandwidths: 20KHz, 3MHz, and 40MHz. The optical train for the sensitivity measurements at 514nm is shown in Figure 6. The EG&G radiometer was placed in the incoming collimated laser beam to obtain a reference RMS reading and subsequently an irradiance level. The EG&G was then removed from the beam path exposing the LIR to that same irradiance to radiation, a signal-to-noise ratio was then calculated after observing the peak amplitude of the signal created by the radiation. Given this information the Minimum Detectable Signal (MDS) can then be computed. The results of the test are summarized in Table 1 for all gain and bandwidth levels.

(b) 532nm sensitivity measurements could not be conducted due to failure of the 532nm channel during testing.



1800 Steps in Table Position:

1. Measured 12.6 divisions

2. Thus $1800/12.6 = 142.85$ Steps/Division

   and

   $$\frac{142.85 \text{ Steps/Division}}{600 \text{ Steps/Degree}} = .238 \text{ Degrees/Division}$$

3. On FOV curve at 3dp points:

   2 4/5 divisions measured

   Therefore FOV = 2 4/5 x .238 + .6664°

   or

   FOV = .6664°/57°/rad = 11.7 mRad

Figure 6. FOV Measurement

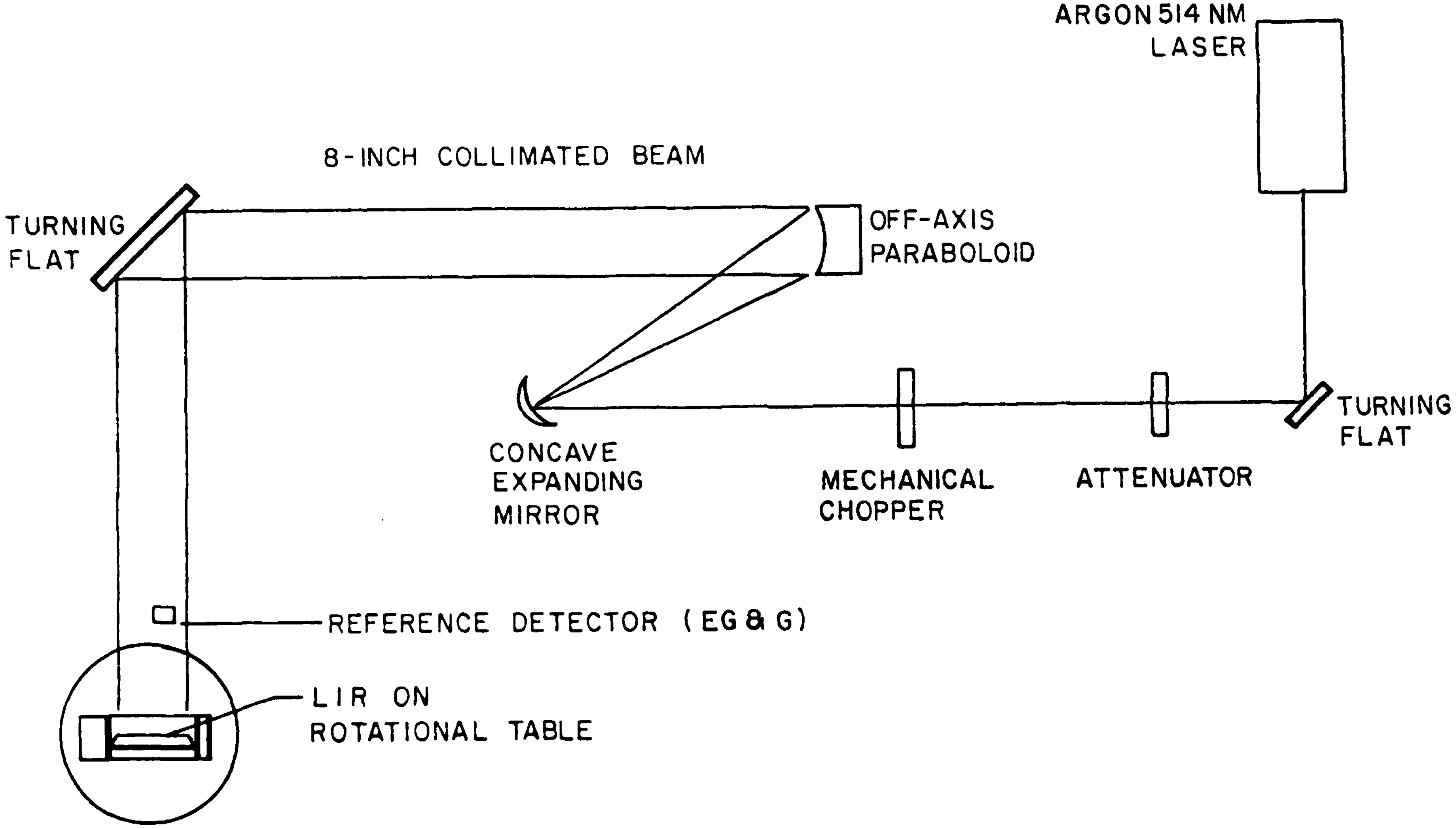


Figure 7. Configuration for Frequency Response Measurements

TABLE 1. RESULTS OF MINIMUM DETECTABLE SIGNAL TEST

WAVELENGTH = 514nm

SETTING: Minimum Gain

BANDWIDTH EG&G RMS VALUE (V)	EG&G * PEEK-PEEK(V)	CONVERSION FACTOR	IRRADIANCE W/cm^2	SIGNAL/NOISE RATIO	MDS
20KHz $2.2x10^{-10}$	$6.2x10^{-10}$	$.156x10^{-3}$	$3/97x10^{-6}$	$\frac{150mv}{10mv} = 15$	$2.64x10^{-7}$
3MHz $1.1x10^{-9}$	$3.11x10^{-9}$	$.156x10^{-3}$	$1.99x10^{-5}$	$\frac{1.2v}{120mv} = 10$	$1.99x10^{-6}$
40MHz $1.1x10^{-9}$	$3.11x10^{-9}$	$.156x10^{-3}$	$1.99x10^{-5}$	$\frac{1.5v}{.5v} = 3$	$6.64x10^{-6}$

SETTING: Auto Gain

BANDWIDTH EG&G RMS VALUE (V)	EG&G * PEEK-PEEK(V)	CONVERSION FACTOR	IRRADIANCE W/cm^2	SIGNAL/NOISE RATIO	MDS
20KHz $.7x10^{-11}$	$1.9x10^{-11}$	$.156x10^{-3}$	$1.21x10^{-7}$	$\frac{200mv}{10mv} = 20$	$6.05x10^{-9}$
3MHz $1.1x10^{-11}$	$3.1x10^{-11}$	$.156x10^{-3}$	$1.99x10^{-7}$	$\frac{900mv}{100mv} = 9$	$2.21x10^{-8}$
40MHz $1.1x10^{-11}$	$3.11x10^{-11}$	$.156x10^{-7}$	$1.99x10^{-7}$	$\frac{1.2v}{.5\ v} = 2.4$	$8.3x10^{-8}$

SETTING: Maximum Gain

BANDWIDTH EG&G RMS VALUE (V)	EG&G * PEEK-PEEK(V)	CONVERSION FACTOR	IRRADIANCE W/cm^2	SIGNAL/NOISE RATIO	MDS
20KHz $1.5x10^{-11}$	$4.24x10^{-11}$	$.156x10^{-3}$	$2.72x10^{-7}$	$\frac{400mv}{10mv} = 40$	$6.8x10^{-9}$
3MHz $1.5x10^{-11}$	$4.24x10^{-11}$	$.156x10^{-3}$	$2.72x10^{-7}$	$\frac{.92mv}{100mv} = 9.2$	$3.02x10^{-8}$
40MHz $1.5x10^{-11}$	$4.24x10^{-11}$	$.156x10^{-3}$	$2.72x10^{-7}$	$\frac{1.2v}{.5v} = 2.4$	$1.31x10^{-7}$

* p-p Value = $\frac{2x\ Rms\ value}{.707}$

(c) 1064nm sensitivity measurements were performed using two methods: a synthetic optical gain radiometer presently under development by the Electro-Optics Laboratory at Wright-Patterson AFB designed to perform low-light-level calibration radiometry, and a traditional blackbody calibrator shown in Figure 3. These two methods permitted comparison between low frequency and high frequency sensitivity. The SR-2-32 blackbody was operated at a temperature of 800 C thus providing an irradiance level of 1.3×10^{-9} W/cm^{-2}. A model 230 Collimater was used to collimate the beam prior to exposing the LIR. As before, a signal-to-noise ratio is computed and used to determine the MDS. In the auto gain mode, the MDS measured using the blackbody calibrator was 1.27 x 10.-10 W/cm^2. In the same mode, an MDS of 6.22 x 10-9 W/cm^2 was calculated utilizing the Synthetic Optical Gain Radiometer technique. Maximum gain mode measurements were difficult to obtain in the 1064nm channel. Improper biasing of the avalanche methods described are summarized in Tables 2 and 3.

e. **Background Noise Measurements:** The LIR was taken outdoors on a partly sunny day and was exposed to sunlight illumination. Noise measurements were made at the 1064nm and 514nm channels at all gain and bandwidth settings. The results are found in Table 4. With these results a comparison can be made between the systems dynamic range under dark and light conditions thus determining the limiting dynamic range of the LIR.

f. **System Dynamic Range:**

(1) We found that the LIR saturated at 4 volts signal. Given this fact, the system dynamic range can be calculated for all bandwidths and gain levels. Comparison of dynamic range under dark and light conditions is considered very important in knowing the system limitations during outdoor field experiments. For the 514nm channel, the best dynamic range under dark conditions was 52.04db for all gain selections at 20KHz bandwidth. A dynamic range of 48.5db is obtained under sunlight background illumination conditions. The worst-case dynamic range under dark conditions for the 514nm channel was 18.06db at maximum gain in the 40MHz channel, and was only 6.02db under sunlight conditions.

(2) For the 1064nm channel, a value of 46.02db was found to be the best dynamic range under dark conditions at the auto gain mode and 20KHz bandwidth. A value of 42.4db was obtained under sunlight illumination. Worst-case values for dynamic range under dark and light conditions for the 1064nm channel were found to be 38.06db and 6.02db, respectively, with the LIR set on maximum gain and 3MHz bandwidth.

TABLE 2. BLACKBODY 1064nm SENSITIVITY MEASUREMENTS

BANDWIDTH	GAIN SETTING	BLACKBODY IRRANDIANCE (W/cm^2)	Vp-p/NOISE	MDS (W/cm^2)
20KHz	AUTO	$1.268x10^{-9}$	$\frac{200mv}{20mv} = 10$	$1.268x10^{-9}$
20MHz	MAX	$1.268x10^{-9}$	$\frac{1.5v}{50mv} = 28$	$4.53x10^{-10}$
3MHz	AUTO	$1.268x10^{-9}$	$\frac{225mv}{20mv} = 1125$	$1.127x10^{-10}$
3MHz	MAX	$1.268x10^{-9}$	$\frac{1.6v}{50mv} = 32$	

TABLE 3: SYNTHETIC OPTICAL GAIN RADIOMETER 1064 SENSITIVITY MEASUREMENTS

DET 002 Irradiance $5.90x10^{-5}$ W/cm^{-2}
DET 001 Irradiance $1.92x10^{-3}$ W/cm^{-2}
DET 001/DET 00Z = 3.25 x 107

BANDWIDTH	GAIN SETTING	S/N RATIO	DET 001 IRRADIANCE	EXPECTED DET 002 IRRADIANCE (W/cm2	MDS (W/cm^2)
3MHz	AUTO	$\frac{600mv}{100mv} = 6$	$2.02x10^{-1}$	$6.22x10^{-9}$	$1.03x10^{-9}$
3MHz	MAX	$\frac{16}{100mv} = 10$	$2.02x10^{-1}$	$6.22x10^{-9}$	$6.22x10^{-10}$

TABLE 4. SUNLIGHT BACKGROUND ILLUMINATION TEST

WAVELENGTH (um)	GAIN	BANDWIDTH	NOISE
1.06	Auto	20KHz	30mv
1.06	Max	20KHz	250mv
1.06	Min	20KHz	10mv
1.06	Auto	3MHz	400mv
1.06	Max	3MHz	2v
1.06	Min	3MHz	150mv
1.06	Auto	40MHz	2v
1.06	Max	40MHz	2v
1.06	Min	40MHz	800mv

WAVELENGTH (nm)	GAIN	BANDWIDTH	NOISE
514	Auto	20KHz	40mv
514	Max	20KHz	40mv
514	Min	20KHz	15mv
514	Auto	3MHz	400mv
514	Max	3MHz	400mv
514	Min	35MHz	150mv
514	Auto	40MHz	2v
514	Max	40MHz	2v
514	Min	40MHz	800mv

SECTION IV: SUMMARY AND RECOMMENDATIONS

The LIR was found to have good performance in light of its simplistic design. The 11-mrad FOV exceeds the contractor's specification. The measured system sensitivity at different bandwidths and gain modes is more than adequate for most Air Force laser measurement scenarios. Since typical Air Force field test requirements dictate dynamic ranges of 120db to 160db, the system has limited applications. Future hardware improvement considerations might include selection of a photodetector other than avalanche photodiodes. In addition, optical methods for input signal conditioning should be considered.

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